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The Future of Unmanned Aircraft Systems in Support of the Marine Expeditionary Unit

3 November 2011

by

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Abstract

The USMC Marine Expeditionary Unit (MEU) is commonly referred to as "the nation's 911 force." It must be capable of executing a full spectrum of missions from low-intensity humanitarian assistance and noncombat evacuations to high-intensity major combat operations. The MEU's structure and equipment are designed around this multi-mission requirement. However, the USMC owns the fixed-winged Shadow unmanned aircraft system (UAS) and is in the process of acquiring a small fixed-wing UAS, the small tactical UAS to provide intelligence, surveillance, and reconnaissance. The USMC is also researching a cargo resupply UAS based on helicopter technology. The USMC focus on single-mission UAS does not fit with the MEU's mission requirements. This thesis will examine MEU mission requirements and recommend a UAS capability set that best supports MEU operations. From this recommended set of requirements, the thesis will use a cost analysis to determine a future UAS program of record.

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List of Acronyms and Abbreviations

ACE	Aviation Combat Element
ANGLICO	Air Naval Gunfire Liaison Company
ARG	Amphibious Readiness Group
BLOS	Beyond Line of Sight
CAS	Close Air Support
CASEVAC	Casualty Evacuation
CE	Command Element
CER	Cost-Estimating Relationship
CMC	Commandant of the Marine Corps
CO	Commanding Officer
COTS	Commercial off-the-shelf
CSAR	Combat Search and Rescue
CUAS	Cargo Unmanned Aircraft System
DASA-CE	Office of the Deputy Assistant of the Army for Cost and Economics
DoD	Department of Defense
DON	Department of the Navy
E-MIO	Expanded Maritime Interdiction Operations
ESG	Expeditionary Strike Group
EW	Electronic Warfare
FAC(A)	Forward Air Controller (Airborne)
FARP	Forward Arming Refueling Point
FLIR	Forward-Looking Infrared
FY	Fiscal Year
GCE	Ground Combat Element
GS&E	Ground Support and Equipment
HA/DR	Humanitarian Assistance/Disaster Relief
IOC	Initial Operating Capability
ISR	Intelligence, Surveillance, and Reconnaissance
JFC	Joint Force Commander
JSF	Joint Strike Fighter
LAV	Lightly Armored Vehicle

LCE	Logistics Combat Element
MAGTF	Marine Air-Ground Task Force
MCCDC	Marine Corps Combat Development Command
MC	Monte Carlo
MEB	Marine Expeditionary Brigade
MEDEVAC	Medical Evacuation
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MOS	Military Occupational Specialty
MRUAS	Medium Range Unmanned Aircraft System
MSC	Major Subordinate Commands
NEO	Noncombatant Evacuation Operation
NRE	Non Recurring Engineering
NSFS	Naval Surface Fire Support
NTISR	Non Traditional Intelligence, Surveillance, and Reconnaissance
OMFTS	Operational Maneuver from the Sea
PDF	Probability Distribution Function
SAR	Synthetic Aperture Radar
SE/PM	System Engineering/Program Management
SOTG	Special Operations Training Group
SOP	Standard Operating Procedure
STOM	Ship to Objective Maneuver
STUAS	Small Tactical Unmanned Aircraft System
TRAP	Tactical Recovery of Aircraft and Personnel
TTP	Techniques, Tactics, and Procedures
UAS	Unmanned Aircraft System
U.S.	United States
V/STOL	Vertical/Short Take-off
VMU	Marine Unmanned Aircraft Squadron
VTUAS	Vertical Take-off Unmanned Aircraft System
WBS	Work Breakdown Structure
XO	Executive Officer

I. Introduction

It must be considered that there is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things.

—Niccolo Machiavelli (1952, p. 55)

A. Purpose

The United States Marine Corps (USMC) Marine Expeditionary Unit (MEU) is commonly referred to as "the nation's 911 force." It must be capable of executing a full spectrum of missions, from low-intensity humanitarian assistance and noncombat evacuations to high-intensity major combat operations. Its structure and equipment are designed around this diverse mission requirement. One of the four organizations in an MEU, the aviation combat element (ACE), meets this requirement by maintaining a blend of aircraft platforms that operate throughout this diverse spectrum. Each platform is specifically designed to execute multiple missions to minimize the need for several different assets on the constrained space of the Navy ships that support an MEU.

Currently, the USMC does not have unmanned systems that support the MEU. The USMC operates a variety of unmanned aircraft systems (UASs), including a small fixed-wing UAS, the small tactical UAS (STUAS), and a larger fixed-wing UAS called the Shadow RQ-7. The USMC is also researching a cargo resupply UAS based on helicopter technology. The Marine's focus on single-mission UASs does not fit with USMC mission requirements and will prevent full employment of future systems due to limited space on Navy ships.

Although the USMC has several UAS programs, it needs to develop a multi-mission system and establish this UAS as the program of record.

B. Objectives

In this project, I identify a future multi-mission UAS to support the warfighter. The success of future MEUs and, in turn, the success of the USMC relies on current and relevant equipment. This equipment must fit the operational needs of the MEU without exceeding the constraints of the shipboard environment.

C. Methodology

The ideal location to establish the requirements for a UAS program of record is arguably in the Marine Corps' most arduous environments: aboard ship with an MEU. The MEU is the backbone of USMC doctrine and is based on the concept of the Marine Air-Ground Task Force (MAGTF). An analysis of the MEU's missions provides the most accurate picture of what a future UAS should look like. I will use a multi-step methodology to locate a multi-mission platform that can achieve the full spectrum of MEU mission requirements.

My methodology for this thesis included three steps: (1) determine required UAS capabilities, (2) construct a basic UAS design, and (3) determine the cost of the design.

In the first step, define UAS capabilities, I surveyed Marine officers who are familiar with MEU and UAS operations. The survey responses reveal capability requirements that could be transferred from manned aircraft to a future unmanned system.

During the capabilities definition step, I also interviewed current and past MEU commanders to identify capability shortfalls they perceive or scenarios in which they anticipate using an unmanned platform instead of a manned aircraft.

In the second step of this research, I analyzed the recommended capabilities and then designed a platform that supports these capabilities. Some possible options for this design include rotary-wing or fixed-wing platforms that vary in size

from small to very large. Using the capabilities identified in step one, I determined the systems that need to be attached to the new UAS.

Based on the basic design concept, I conducted a parametric analysis to determine an average unit cost for the new UAS. Numerous existing cost-estimating relationships provide the necessary cost data. The cost data from these relationships provide a credible cost estimate for acquisition program decision makers.

D. Summary

As the USMC postures itself for the future, it must ensure that decisions made concerning unmanned systems support mission success. The future of manned USMC aviation is set by choices with the MV-22, CH-53K, and the Joint Strike Fighter (JSF). All manned platforms are capable of executing multiple missions in support of MEU operations, and the unmanned systems should be similarly capable.

As the United States (U.S.) begins to de-mobilize from a decade of conflict abroad, the country will rely on the MEU to be the face of U.S. and USMC presence overseas. The Marines will be asked to support this central role in foreign policy while defense budgets shrink. The USMC will be asked to do more with less, again highlighting the need for one multi-mission-capable program of record for UAS.

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II. Literature Review

There has been speculation that war itself may not have a future and is about to be replaced by economic competition among the great "trading blocks" now forming in Europe, North America, and the Far East. This . . . view is not correct. Large-scale, conventional war—war as understood by today's principal military powers—may indeed be at its last gasp; however, war itself, war as such, is alive and kicking and about to enter a new epoch.

—Martin van Creveld (1991, p. 2)

A. Strategic Policy and Vision

The Department of Defense (DoD) regularly publishes a roadmap establishing its vision for unmanned systems. In its most current roadmap document, the DoD made this statement:

> The vision for the DoD is that unmanned systems will provide flexible options across operating domains, enabling the Warfighter's execution of assigned missions. Unmanned systems will be integrated across domains and with manned systems, providing the Joint Force Commander (JFC) with unique and decisive capabilities. (DoD, 2009, p. 7)

This joint vision fully supports the Navy and USMC's overarching tenets of operational maneuver from the sea (OMFTS) and ship-to-objective maneuver (STOM). For successful execution of OMFTS or STOM, an unmanned system will need systems that are flexible enough to operate across all domains.

The USMC's vision also mandates aggressive exploration into the application of unmanned systems (Commandant of the Marine Corps [CMC], 2008, p. 19). More specifically, the USMC is examining ways to use UAS to extend "the range and effectiveness of naval surface fire support" (Marine Corps Combat Development Command [MCCDC], 2009, p. 29) or to improve ACE performance by relying on unmanned systems to reduce the footprint of the MAGTF in expeditionary operations (Deputy Commandant for Combat Development and Integration, 2010).

B. Marine Expeditionary Unit

The MEU has a long history that goes back to 1776, when embarked Marines landed on the beaches of New Providence, The Bahamas (Simmons & Moskin, 1998, p. 7). Since that first landing, Marines have been embarking on Navy ships and deploying around the world to provide the U.S. with a force projection instrument for global peace.

An MEU is designed around the concept of a MAGTF: a multi-faceted task force has all the elements necessary to be self-sufficient in combat. There are four elements to all MEUs: a ground combat element (GCE), a logistics combat element (LCE), command element (CE), and an aviation combat element (ACE).

1. Ground Combat Element

The heart of the MEU is the GCE. The GCE for an MEU consists of an infantry battalion that is reinforced with artillery, reconnaissance, engineers, armor, and assault amphibian units (USMC, 1998, p. 3).

2. Logistics Combat Element

This element is the task-organized logistical and sustainment unit for the MEU. The LCE can provide support either from Navy ships at sea or from expeditionary locations ashore (USMC, 1998, p. 3).

3. Command Element

The command element contains the necessary capabilities to command and control the MEU. The CE is also task organized and can consist of intelligence, communication, and administration units (USMC, 1998, p. 3).

4. Aviation Combat Element

The ACE is a task-organized and reinforced Marine squadron that normally consists of both rotary-wing and fixed-wing aircraft. A common MEU ACE squadron

has "transport, utility, and attack helicopters, a detachment of vertical/short takeoff and landing (V/STOL) fixed-wing attack aircraft" as part of its table of equipment (TE; USMC, 1998, p. 3). Table 1 lists all of the characteristics and armament of the traditional aircraft found on the ACE's TE.

Table 1. MEU ACE Aircraft Performance Characteristics

Aircraft	Payload	Speed (knots)	Range (nm)	Ceiling (ft)	Armament
MV-22 (IHS, 2010)	24 troops 10000 lbs internal 15000 lbs external	250	880	26,000	7.62 mm MG (Ramp/belly mounted)
CH-53E/K (IHS, 2011c)	37 troops 30000 lbs internal 32000 lbs external (35000lbs K model)	150	540	18,500	.50 cal (Window/Ramp)
AH-1W (IHS, 2011b)	4450 lbs	152	317	14,000	20mm gun / AGM-114 HELLFIRE / TOW / AIM-9 Sidewinder / AGM-122 Sidearm / 2.75in rockets
AH-1Z (IHS, 2011b)	6300 lbs	170	370	14,000	20mm gun / AGM-114 HELLFIRE / TOW / AIM-9 Sidewinder / AGM-122 Sidearm / 2.75in rockets
UH-1N (IHS, 2011d)	3290 lbs	110	276	12,600	.50 cal / 7.62mm / 2.75 in rockets
UH-1Y (IHS, 2011d)	6660 lbs internal 5000 lbs external	198	350	20,000	.50 cal / 7.62mm / 2.75 in rockets
AV-8B (IHS, 2011e)	17,000 lbs (STO)	575	90-627 (config. dependent)	50,000	25mm cannon / AIM-9 Sidewinder / AGM-65 Maverick / GBU-38 JDAM (500lb family of bombs)
F-35B (IHS, 2011a)	28500 lbs	1043	450	60,000	25mm cannon / JDAM family of bombs / AIM-9 Sidewinder / GBU-12 Paveway II / AGM-154 JSOW

The ACE's mission is to be prepared to execute some or all of the six functions of Marine aviation: assault support, control of aircraft and missiles,

offensive air support, anti-air warfare, electronic warfare, and air reconnaissance (USMC, 1998, p. 3).

C. Unmanned Aircraft Systems

Research, development, and procurement of UASs have been volatile in the DoD for the past decade. This is demonstrated by the large amounts of money spent on UAS programs. In the span of 2009–2013 (budgeted and planned), the DoD has budgeted over $5 billion on UAS research and development and close to $9 billion on procurement.

The Department of the Navy (DON), including the USMC, also is dedicated to the procurement of UAS. In 2011, the DON established the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER) at the Naval Postgraduate School for the sole purpose of furthering the Navy's UAS efforts (Under Secretary of the Navy [USN], 2011).

As part of the formation of CRUSER, the Under Secretary of the Navy (2011) established goals for the development of DON/Joint UAS capabilities. These goals include the following:

- Develop common system components across the Medium Range UAS (MRUAS) and Cargo UAS (CUAS) to achieve maximum capability for service/joint mission requirements, with a goal of achieving a common "truck" for both missions.
- Develop a Group 4 Vertical Lift Seabased Cargo UAS-CUAS initial operating capability (IOC) 2016
- Develop a Group 4 Expeditionary Electronic Warfare (EW)/Intelligence Surveillance, Reconnaissance (ISR)/Strike–Marine Expeditionary Force (MEF)/Marine Expeditionary Brigade (MEB) UAS IOC 2018

1. Vehicles

Unmanned systems are defined by the air, surface, or subsurface vehicles that move the complex systems and payloads required for the mission. The primary

unmanned aircraft vehicles have been fixed-wing aircraft. Table 2 provides examples of four UASs: two fixed-wing aircraft and two vertical-takeoff aircraft.

Table 2. Unmanned Aircraft Systems

	Weight (lbs)	Range (nm)	Speed (max knts)	Ceiling (ft)	Endurance (hrs)	Pay-load (lbs)	Systems	Armament
MQ-1 Predator (U.S. Air Force)	2250	500	118	25000	24 clean, 16 w/ external	450	EO/IR/SAR	AGM-114 HELL-FIRE
RQ-7 Shadow (USMC)	375	67	110	14000	5-6	60	EO/ IR	
MQ-8 Firescout (U.S. Navy)	3150	150	117	20000	6+	600	EO/ IR/ laser desig. & range finder/ Radar	
A-160 Humming-bird (USMC)	5600	>1000	140	30000	20+	300-1000	EO/IR	

Notes. I created this table based on information found in *FY2009-2034 Unmanned Systems Integrated Roadmap* (DoD, 2009, pp. 51–75). Both the MQ-8 Firescout and A-160 Hummingbird are still under research and development and in different phases of the acquisition process.

Because of the effectiveness of improvised explosive devices (IED), the USMC has recently shown interest in vertical-takeoff or rotary-wing vehicles to carry cargo in Afghanistan. However, unlike the development of fixed-wing UASs, the research and development of rotary-wing UASs has focused on the utilization of production helicopters.

2. Systems

The predominant use of unmanned systems is to support intelligence gathering and to make use of imaging technology. Imaging systems consist primarily of electro-optic (EO)—also known as visible spectrum—cameras and infrared (IR) cameras.

As unmanned platforms become more capable, the DoD explores new UASs with increased mission capabilities. Expanded UAS capabilities include targeting, weaponization, and improved reconnaissance with the synthetic aperture radar (SAR; DoD, 2009, p. xiii).

3. Future

The future of unmanned systems is defined by a list of challenges and risks. Some of the challenges are identifying requirements, preventing duplication, and creating new career paths for service members. The risks revolve around the fast-paced advancement of technology in the UAS community.

The future developers of UAS will have to tackle numerous challenges, but the ever-changing and unclear requirements are most serious. As technology advances and increased capabilities become available for unmanned systems, the requirements change. These changes lead to requirement creep, which complicates the acquisition process because UASs become more costly (DoD, 2009).

Another issue for the future is duplication. Again, as technology develops and stakeholders push for a fast supply of UASs, organizations and services could duplicate UAS capabilities, resulting in a rise in unit costs and consequent problems in the acquisition process (DoD, 2009).

The last major concern for UAS progress is the career path of the service members who work with UAS. Currently, no UAS-specific job specialties exist in any service. Primary controllers spend one tour working on UAS and then return to their previous occupational specialty. For UAS workers to create a professional organization with an experience base for future development, a career path must be established (DoD, 2009).

The final topic of discussion is the future risks associated with UAS. This technology is advancing in leaps and bounds. This fast-paced advancement, combined with the lethargic acquisition process, has the inherent risk of causing the

DoD to acquire unmanned systems that are obsolete by the time they are fielded (DoD, 2009).

D. Cost Estimation

In the acquisition community, cost estimation is the method used to determine costs of programs. There are four main methods to determine costs: (1) expert, (2) analogy, (3) parametric, and (4) engineering breakdown. The primary method for my research is the parametric method. The parametric method examines several systems that are similar in nature to the program that is under review. The different costs of these similar systems are used to determine a cost-estimating relationship that can be applied to any new system to estimate the costs of these new systems.

1. Work Breakdown Structure

One technique used to determine cost estimates is breaking a system into its different elements. The costs of the elements can then be used to determine the total system costs. A work breakdown structure (WBS; an example of which is shown in Figure 1) "reflects the requirements, what must be accomplished to develop a program, and provides a basis for identifying resources and tasks for developing a program cost estimate" (Government Accountability Office [GAO], 2009). WBS models and their associated cost elements are considered one of the best practices for estimating the costs of programs and managing them over their life cycle (GAO, 2009).

- Hardware
  - Air Vehicle
    - Airframe
      - Fuselage
      - Wings
      - Tail
      - Landing Gear
    - Propulsion
      - Reciprocating
      - Turboshaft
    - Electrical
    - Navigation/Flight Control
    - Data Link
    - Integration & Assembl;y
- Non-Recurring Engineering (NRE)
  - Hardware
  - Software
- Development Support
  - Support Equipment
  - System Test & Evaluation
  - Training
  - Data
  - Spares
  - SE/PM

Figure 1. UAS Work Breakdown Structure
(Horak, Harbour, & Holcomb, 2007, p. 3)

2. Uncertainty

The Weapon System Acquisition Reform Act of 2009 (WSARA, 2009, § 2334) states that those who estimate costs must

> disclose in accordance with paragraph (2) the confidence level used in establishing a cost estimate for a major defense acquisition program or major automated information system program, the rationale for selecting such confidence level, and, if such confidence level is less than 80%, the justification for selecting a confidence level of less than 80%.

The mandate to select a confidence level suggests that there is a degree of uncertainty in cost estimation. The simple definition of cost estimation as a prediction of a future value of cost in itself should be enough to highlight the occurrence of uncertainty.

The methods used to derive costs bring uncertainty into cost estimation. For example, in this research I used the parametric method to determine the cost of UAS. When one uses the parametric method, one tries to compare costs of previous systems to estimate the cost of a new program. The variables and values used to define the cost of old systems will not be the same as the variables and values of the new system. Two factors drive uncertainty in this scenario. The first factor is physical differences between old and new systems that affect the values of the variables that will be used for the cost estimations. The second factor driving uncertainty, which for cost estimators is the biggest driving factor, is that when the cost estimation is complete, the resulting values for the variables have rarely been determined.

The occurrence of uncertainty led the Cost Analysis Improvement Group to create certain requirements:

> Areas of cost estimating uncertainty will be identified and quantified. Uncertainty will be quantified by the use of probability distributions or ranges of cost. The presentation of this analysis should address cost uncertainty attributable to estimating errors; e.g., uncertainty inherent with estimating costs based on assumed values of independent variables outside data base ranges, and uncertainty attributed to other factors, such as performance and weight characteristics, new technology, manufacturing initiatives, inventory objectives, schedules, and financial condition of the contractor. The probability distributions, and assumptions used in preparing all range estimates, shall be documented. (Assistant Secretary of Defense, 1992, p. 33)

a. Monte Carlo Method/Probability

The Monte Carlo (MC) method is a common approach used to determine the probability distribution, or range, of costs. MC provides the full "range of possible outcomes and the probabilities they will occur for any choice of action" (Palisade, 2011). The MC method can determine the full range of outcomes by randomly selecting values for the variables found in the cost-estimating relationships (CER) chosen to define the costs of each level of the WBS.

For each variable, there is a range of expected values. The probability distribution functions (PDF) of the variables are the tools that MC uses to derive the final CER distributions. Palisade (2011), a maker of risk software, defines the common variables' probabilities distributions that I used in this research:

- Normal (or "bell curve"). User-defined mean or expected value and a standard deviation describe the variation about the mean (Palisade, 2011).
- Uniform. All values have an equal chance of occurring, and the user selects a minimum and maximum (2011).
- Triangle. User-defined minimum, most likely, and maximum values (2011).
- Custom. User-defined specific values that occur and the likelihood or probability of each (2011).

Once the variables have been defined according to the probabilities, values are selected randomly from the input variables distributions and the CER is calculated to determine a single iteration solution. The MC method then repeats the process thousands of times. Each iteration selects different random values for the variables. The results of the thousands of iterations define the distribution or range of outcomes and the corresponding probabilities for those outcomes (Palisade, 2011).

There are several benefits to the MC method. One is the ability to graph the outcomes of the iterations. The graphic output allows the user to easily determine the most likely or more probable solution or cost. A second benefit is sensitivity analysis. MC permits a user to examine how sensitive the cost estimate is to changes in the variables used to determine the estimate (Palisade, 2011).

E. Conclusion

As the USMC continues to develop its UAS programs, it must emphasize MEU operations. When the conflicts in Iraq and Afghanistan end, the USMC will

return to its mandated mission as the nation's 911 force; ready to execute according to the will of the President of the United States.

Numerous studies have identified technology gaps that limit the USMC's ability to achieve mission success. New and improved multi-mission aircraft are overloading Navy ships, and current UAS designs do not support MEU operations. As the USMC continues to explore future UAS, the service must research, develop, and procure a multi-mission unmanned aircraft that relieves overloading, but that also fills the gaps in the manned and unmanned platforms currently deployed with the MEU. A multi-mission UAS will ensure the future success of the MEU and, thus, the USMC.

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III. Research Methodology, Scope, and Limitations

Word came on May 27 that another revolution was in full swing at Bluefields, on the east coast of Nicaragua. We received orders to leave at eight thirty in the morning and by eleven thirty were on our way—two hundred and fifty officers and men. Mrs. Butler had [gone] . . . to do some shopping. When she returned at noon, I was gone.

—Smedley D. Butler (as cited in Thomas, 1933, p. 27)

A. Introduction

The MEU's operations and environments are unique. Three MEUs are always deployed throughout the world, working in different climates and places. This uniqueness makes deciding what type of UAS best supports MEU operations a difficult task. To best accomplish this task, I pulled input from as many Marines as possible to determine the capability requirements that (1) are most conducive to being employed by unmanned systems and (2) best support MEU operations. The first step of my research is to define the capability requirements of a new system, and the next step is to analyze the cost of any new systems that have those capabilities.

B. Identification of UAS Configuration for USMC Program of Record

1. Survey

The survey of Marines (Appendix A) is the primary instrument I used to identify the UAS capabilities that would best support the future needs of MEU operations. The survey is divided in two parts. Part one contains individual experience questions that assisted me in categorizing participants' recommendations based on military occupational specialty (MOS), UAS experience, and amount of MEU experience. Part two includes questions that prioritized the mission and capability requirements of an ideal future UAS.

a. SurveyMonkey

To maintain participants' anonymity, I used SurveyMonkey, an online survey. I uploaded all the questions into the online survey and created a link to the survey that I e-mailed to the participants. The link was the method of participating in the survey. SurveyMonkey's protocols have limited ability to prevent users from taking the survey more than once; therefore, the data could be skewed if participants took the survey several times.

b. Selection of Survey Participants

The participants were drawn from across the active duty operating forces of the USMC. I contacted each Marine Expeditionary Force (MEF) for permission to release the survey to units that commonly work with or operate UAS. The units of interest included the following:

- Marine Unmanned Aerial Vehicle Squadrons (VMUs),
- Air Naval Gunfire Liaison Company (ANGLICO),
- Reconnaissance (Recon),
- Special Operations Training Group (SOTG),
- MEU Command Element, and
- MEU Battalion Landing Teams (BLTs).

With MEF approval, I identified and contacted the executive officers (XOs) of each unit to distribute the survey. Officers were the primary audience in each organization. The SurveyMonkey link was embedded in the e-mail so the XOs could easily forward the e-mail throughout the officer e-mail distribution lists for their units.

These units were the focus of the survey; however, no controls were placed on the survey to prevent participation from other personnel, such as command-level personnel at the different MEFs or individuals at organizations such as the Marine

Corps Combat Development Command (MCCDC). I also released the survey to all Marine students of the Naval Postgraduate School.

c. Survey Size

I planned for a maximum of 500 survey responses. I established a minimum response level of 10% to ensure a large enough sample size to reflect the views of the USMC.

2. Interviews

The final part of the capability requirement definition consisted of interviewing current and past MEU commanders. I considered the MEU commanders as an expert group for this research. They could best answer the questions on how any future UAS would be employed by the MEU and how current systems are being employed. This insight should provide excellent direction on any future program of record that will support these commanders today and in the foreseeable future.

I designed the interview questions (Appendix B) with this idea in mind. There are seven MEU's in the Marine Corps—three each for I MEF in California and II MEF in North Carolina and one for III MEF in Okinawa. I planned for 10 interviews, which included the seven current MEU commanders and the three commanders who most recently completed their tours as MEU COs. The acceptable minimum response to ensure a spread of knowledge and experience was 50%.

C. Cost-Estimating Relationships

Following the determination of future UAS capabilities, the next logical step was to develop a cost estimate for this capability or set of capabilities. To develop this estimate, I established a simple WBS that divided the system into its smallest parts. From the simple WBS, I identified the most important variables, and then established CERs or used current estimating tools. Using a Monte Carlo simulation, I then estimated the costs of future systems with some level of certainty (within determined probabilities).

1. Work Breakdown Structure

For simplicity, I used a basic WBS to derive costs. For the UAS, the most basic WBS consisted of the air vehicle, the sensor and payload, and the ground control equipment. These three pieces are required in order to acquire and employ any UAS system. Assuming that other systems, such as those associated with Systems Engineering, would have similar common WBS item costs, I chose to ignore the other common WBS items.

2. Variables and Relationships

Using CERs from the Office of the Deputy Assistant of the Army for Cost and Economics (DASA-CE), I developed average cost estimates for each work breakdown level. I normalized all cost estimates to fiscal year (FY) 2003 dollars for comparison.

a. Air Vehicle

(1) Variables. I estimated the cost of the first production unit or T1 cost for the platform only. The platform includes all the flying hardware and systems that are required for the operation of the air vehicle. Table 3 lists the variables used to estimate the T1 costs.

Table 3. **Air Vehicle Variable Definitions and Ranges**

Variable	Definition	Range
Empty Wt	Empty weight of air vehicle	**4–4,589 lbs**
MGTOW	Maximum gross takeoff weight	**6–25,600 lbs**
Prod	The air vehicle is a production aircraft (1) or development aircraft (0).	**0 or 1**
Endurance	Length of time air vehicle can fly	**1–38 hrs**
Payload Wt	Maximum weight of payload air vehicle can carry	**1–1,960 lbs**
FF Year	First year the air vehicle flew	**1973–2000**
Range	Maximum range of control system/air vehicle	**0–2,400 naut. mile**
VTOL	The air vehicle is a vertical-takeoff vehicle/helicopter (1) or a fixed-wing vehicle (0)	**0 or 1**

(2) Relationships. I averaged three equations to determine the unit cost of the air vehicle. Equations 1 and 2 directly derived the vehicle's T1 costs, and Equations 3 and 4 estimated the generic unit cost. Equations 1 and 2 were published by Cherwonik and Wehrley (2003; Equation 1 from p. 20 and Equation 2 from p. 16) and Equations 3 and 4 were distributed by Horak et al. (2007; Equation 3 from p. 12 and Equation 4 from p. 10):

$$T1 = 12.55 * (MGTOW)^{0.749 * e(-0.371 * Prod)} \quad (1)$$

$$T1 = 118.75 * (Endurance * Payload\ Wt)^{0.587 *} e^{-0.010 * (FF\ Year-1900) *} e^{(-0.921 * Prod)} \quad (2)$$

$$Unit\ Cost = 0.952 * (1.097 * (Range)^{0.307} * (Payload\ Wt)^{0.399} * (Altitude)^{0.370} * e^{(-0.372 * Prod)} * e^{(0.944 * VTOL)} * Sys\ Qty^{0.848}) / Sys\ Qty \quad (3)$$

$$Unit\ Cost = 0.952 * (0.432 * (Empty\ Wt)^{0.597} * (Altitude)^{0.442} * e^{(-0.372 * Prod)} * e^{(0.636 * VTOL)} * Sys\ Qty^{0.832}) / Sys\ Qty \quad (4)$$

b. Payload and Sensor

(1) Variables. I made the sensor and payload estimates using the 2003 DASA-CE report (Cherwonik & Wehrley, 2003). I used two cost relationships to derive and average sensor cost. These costs are associated with

the modular systems that perform the work (e.g., forward-looking infrared, electro-optics, laser designators, targeting pods, etc.).

The variables used to estimate the payload and sensor costs are found in Table 4.

Table 4. Payload and Sensor Variable Definitions and Ranges

Variable	Definition	Range
Sensor Wt	Weight of sensor	**40–625 lbs**
Tracking	Does the sensor track targets (1) or not (0)	**0 or 1**
Avg Res	The average resolution of the sensor	**.008–.212 nanometers**
Altitude	The maximum altitude the air vehicle will operate	**15–65,000 ft**
FU Year	First year the sensor was used on an air vehicle	**1991-2002**

(2) Relationships. I used the following equations (Cherwonik & Wehrley, 2003, pp. 23–30) to derive and average sensor cost for the unmanned system using the variables in Table 4:

$$\text{Sensor 1} = 24{,}490 * (\text{Avg Res})^{-0.498} * (\text{Altitude})^{0.726} * e^{(1.755 * \text{Tracking})} * e^{-.137 * (\text{FU +Year} - 1900)} \quad (5)$$

$$\text{Sensor 2} = 0.347 * (\text{Sensor Wt.})^{1.575} * e^{(0.473 * \text{Tracking})} \quad (6)$$

$$\text{Sensor 3} = 290.18 * 10^{6} * (\text{Avg Res})^{-0.830} * e^{(1.829 * \text{Tracking})} * e^{-.169 * (\text{FU Year} - 1900)} \quad (7)$$

c. Ground Support and Equipment

(1) Variables. The final level of the WBS is the ground support and equipment (GS&E), which consists of all the ground control equipment (e.g., the joysticks). The variables used to estimate the GS&E costs are found in Table 5.

Table 5. GS&E Variable Definitions and Ranges

Variable	Definition	Range
Range	Maximum range of control system/air vehicle	**0–2,400 naut. miles**
Mobile Base/Tactical	The GS&E is mobile/tactical (1) or not (0)	**0 or 1**
Man Packable	The GS&E is man packable (1) or not (0)	**0 or 1**
Sys Qty	The number of air vehicles per control system	**1–8**

(2) Relationships. For GS&E, I used two DASA-CE cost relationships to determine the average cost per unit of the GS&E. I used the two following Cherwonik and Wehrley equations (2003; Equation 8 from p. 37 and Equation 9 from p. 42):

$$GS\&E1 = 433.4 * (Range)^{0.507} * e^{(0.398 * Mobile\ Base/Tactical)} * e^{(-3.480 * Man\ Packable)} \quad (8)$$

$$GS\&E2 = 435.3 * (MGTOW * Syst\ Qty)^{0.318} * e^{(-3.83 * Man\ Packable)} \quad (9)$$

3. Monte Carlo and Crystal Ball

I derived the cost probabilities for different variable combinations by running the WBS costing equations described above through a Monte Carlo simulation. I used Crystal Ball software to execute the Monte Carlo simulation.

In order to create the best fit curves in Crystal Ball, I set the program to simulate 10,000 trials for each run of the simulation. I used variable combinations that best fit the results of the surveys and interviews. I used the results of the Crystal Ball analysis to created tornado diagrams for the Monte Carlo simulation to provide sensitivity analysis for each variable.

D. Summary

In this chapter, I established a method to determine a future UAS program of record. Using the desired missions given to me by Marines and MEU commanders, I establish the capabilities for this future program. My cost analysis helps to determine the cost-effective capabilities this UAS can execute. In the next chapter, I describe the survey results and provide the analysis that I performed using this methodology.

IV. Presentation of Analysis, Data, and Insight

Plans must be simple and flexible. Actually they only form a datum plane from which you build as necessity directs or opportunity offers. They should be made by the people who are going to execute them.

—George S. Patton (1947, p. 399)

A. UAS Capability Analysis

1. Survey Results

The call for participation yielded in 136 survey respondents that had varying occupational specialties, MEU, and UAS experience.

a. Respondent Statistics

There were three specific categories that I examined with respect to the respondents of the survey. The first was the individual military occupational specialties (MOSs), the second was MEU experience, and the third category was UAS experience.

(1) MOS Breakdown. In Figure 2, I break out the MOS categories and the percentages of each that participated in the survey. The MOS categories were divided along commonly accepted lines. Two categories were a combination across several skills sets. The first combination category, combat arms, consisted of any of the 03XX (infantry), 08XX (artillery), 13XX (combat engineer), and 18XX (armor) MOSs. The other combination was the "other" category, and it consisted of 01XX (administration), 11XX (utilities), 30XX (supply), 34XX (financial management), 43XX (public affairs), 60XX (aviation maintenance), and 66XX (aviation logistics).

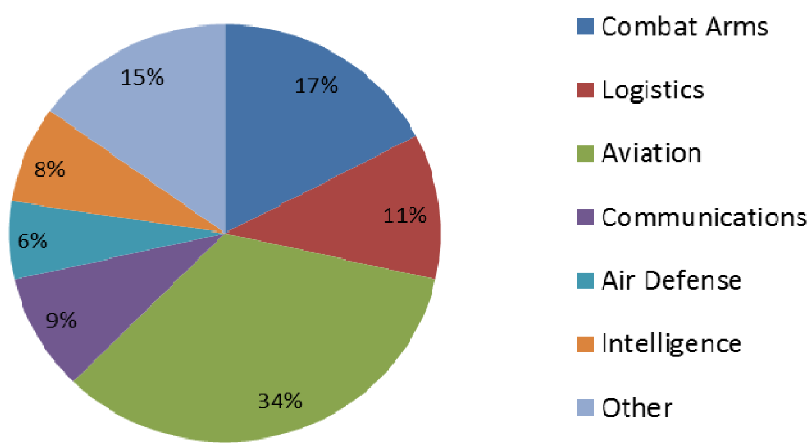

Figure 2. Military Occupational Specialty Breakdown

(2) MEU Experience. Of the 136 respondents, 77 had some level of MEU experience. In Figure 3, I lay out the breakdown of the differing experience levels throughout the sample. The experience level is representative of the current USMC MEU experience, especially with the last decade of ground combat in Operations Iraqi Freedom and Enduring Freedom. Based upon the representativeness of this data, and the focus of the research, I used the MEU experience as the major comparison data when making UAS capability decisions.

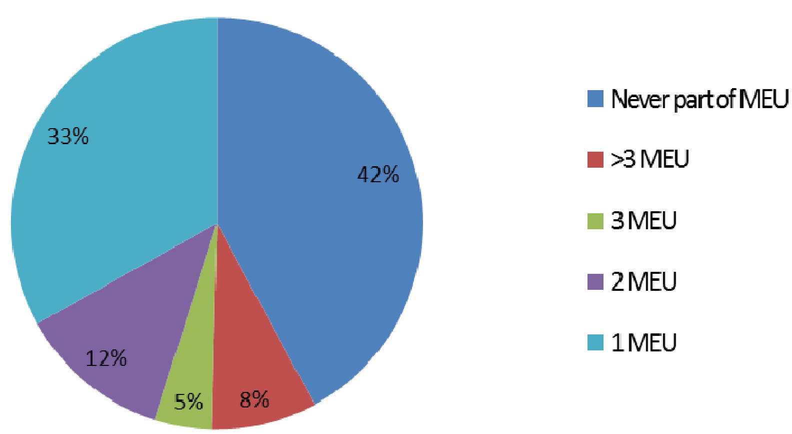

Figure 3. MEU Experience

(3) UAS Experience. When examining the UAS data, 52 of the respondents had not worked with unmanned systems in any respect. In Figure 4 I display the UAS experience breakdown. While creating Figure 5, I further noticed that of those with MEU experience, only one third did not have UAS experience.

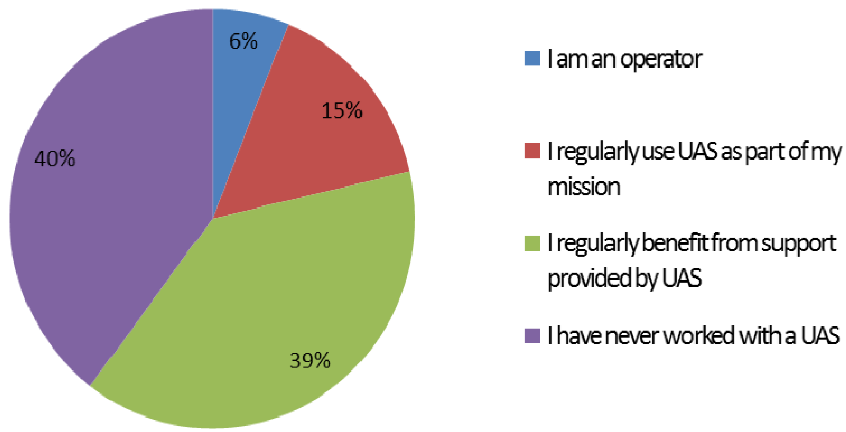

Figure 4. UAS Experience (All Respondents)

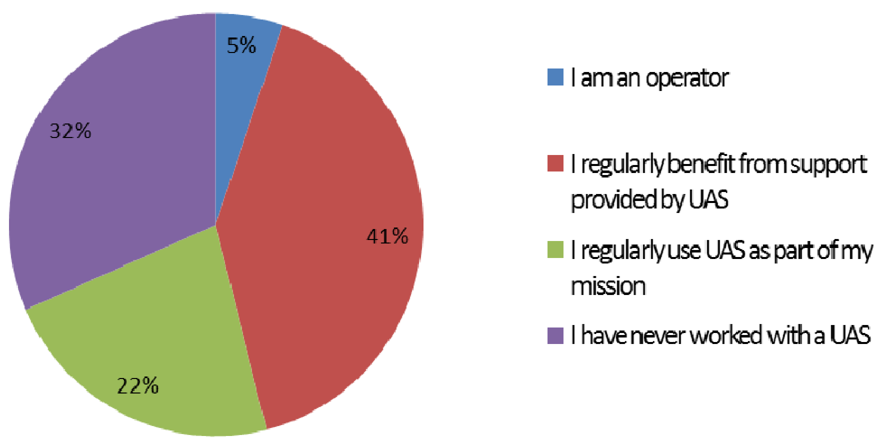

Figure 5. UAS Experience (with MEU Experience)

b. Mission Analysis

The respondents were asked their opinions on which missions they felt were a UAS' primary, secondary, tertiary, quaternary, and least desirable missions. Analysis of all five responses revealed that in all cases the percentage breakdowns

were proportionally the same between all the respondents and those with MEU experience. For simplicity's sake, only the charts representing the data for respondents with MEU experience are included in this chapter. Appendix C contains the charts displaying the survey mission results from all respondents.

For the primary mission, the overwhelming response was ISR at 74% of the respondents, as I show in Figure 6. The mission that the closest number of respondents felt worthy of the primary mission was strike at 12%.

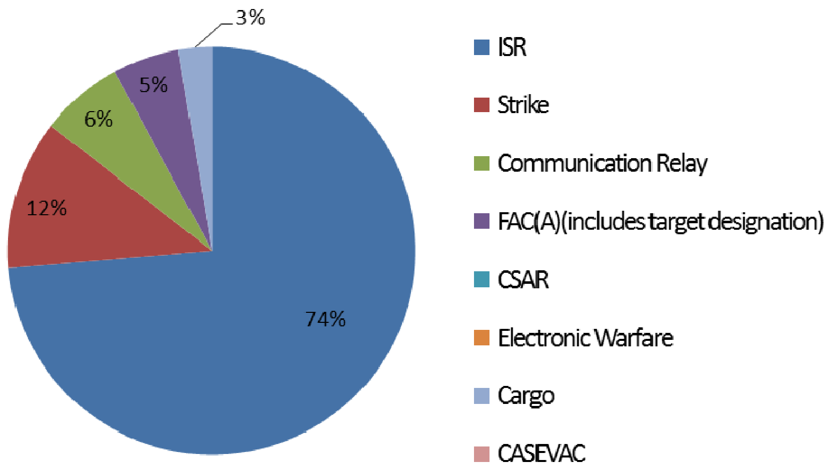

Figure 6. Primary Mission (with MEU Experience)

The secondary mission results, which I show in Figure 7, displayed a wider variance of opinions. The top three survey responses were all within 3% of each other. Respondents chose communication relay most often at 25%, with strike (24%) and FAC(A; 22%) as the other two most commonly chosen secondary missions.

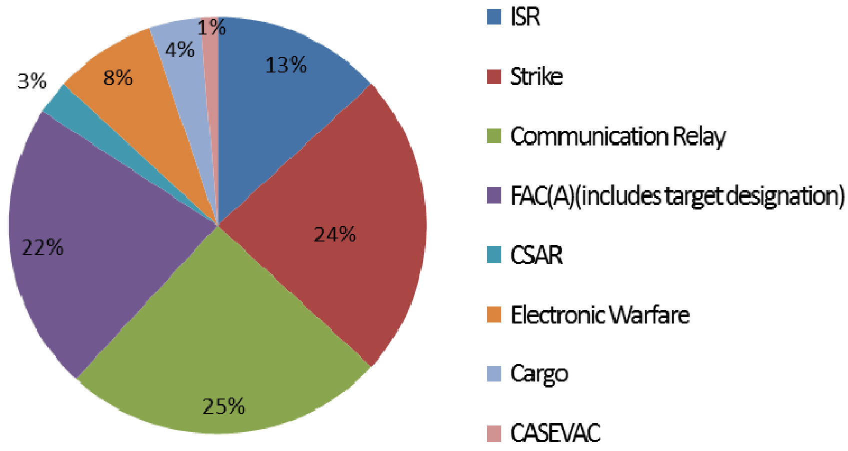

Figure 7. Secondary Mission (with MEU Experience)

In Appendix C, I show that when I considered all respondents' surveys, strike received the highest response for the UAS secondary mission. Figure 7 reflects the needs of the MEU with communication relay as the secondary mission. A survey comment from an aviation command and control officer explains it best: "The greatest benefits UAS's [sic] can provide are to increase situational awareness 'eyes on' and enhance communication."

The tertiary mission survey results were even more diverse than the secondary mission results. Figure 8 shows that there were four major choices for the third mission of MEU. However, in this question the spread between the top three choices was larger than in the secondary mission question. Strike received the most responses at 23%, while communication relay, electronic warfare, and forward air controller (airborne; FAC[A]) were the next high recipients, respectively.

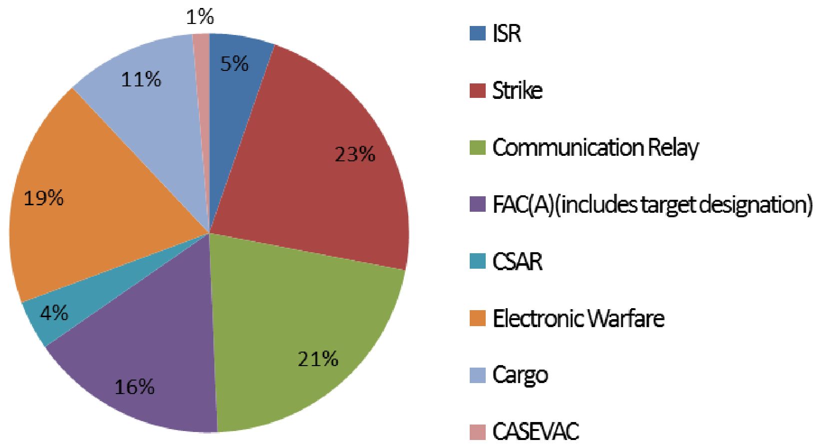

Figure 8. Tertiary Mission (with MEU Experience)

The quaternary mission survey question represented by Figure 9 also received a diverse spread of responses. There were two missions that together received half of the responses: electronic warfare and communication relay. Two other missions received a large proportion of the remaining 50%. They were strike and FAC(A), which combined for 32% of the responses.

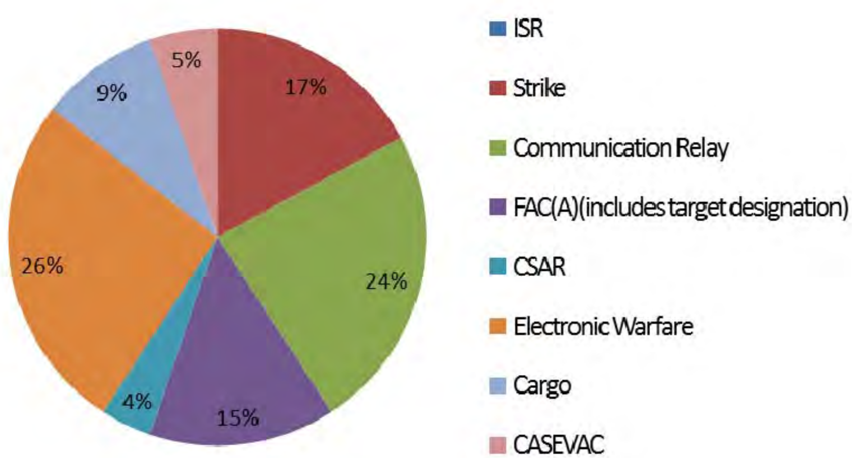

Figure 9. Quaternary Mission (with MEU Experience)

The final survey question polled for the least desired UAS mission. In Figure 10 I display the results of the question: casualty evacuation (CASEVAC) received

the majority of the responses. The next two highest recipients were cargo and combat search and rescue (CSAR), respectively.

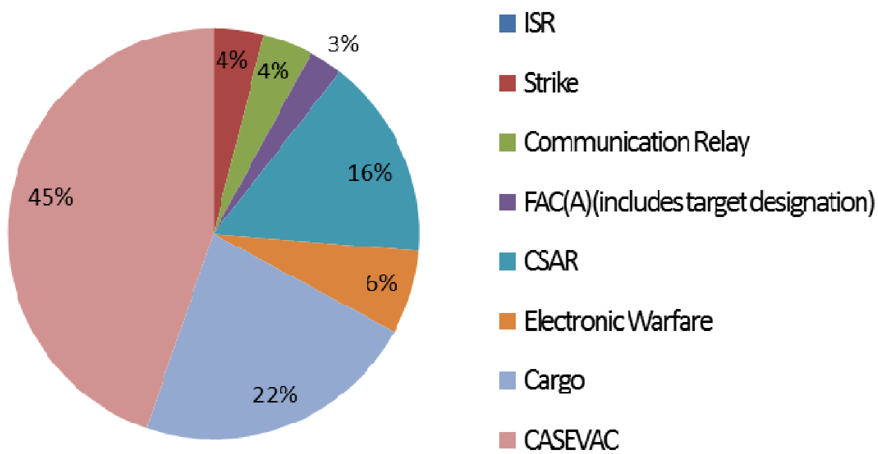

Figure 10. Least Desired Mission (with MEU Experience)

2. Interview Results

Concurrent to the survey execution, I interviewed five MEU commanders to discuss their thoughts on future UAS support of MEU operations. There were several common themes throughout the interviews. Each MEU commander seemed to have similar thoughts on some basic capabilities of a new system, as well as thoughts on ownership and sea basing. A final common theme was the idea that UAS should be an enabler to operations.

a. Basic Capabilities

During my interviews with the MEU commanders, there were a few general capabilities that they felt were requirements on any future UAS.

The first requirement was long endurance. The most common time mentioned was 24 hours. The commanders say the ability to launch a UAS at the end of a ship's established flight window and have it fly until that window opens again the next day as a very good addition to the capability of the MEU/amphibious

readiness group (ARG) team. This would also limit the problems that arise when trying to de-conflict manned and unmanned aircraft operating in a small airspace.

A requirement mentioned along with a long endurance was the ability to launch the UAS over the horizon or beyond line of sight (BLOS). The commanders all agreed that for any UAS to be relevant it needs to be able to operate at the ranges the MEU will operate. Generally speaking, any operation the MEU executes will require UAS to fly BLOS and be controlled BLOS.

b. Ownership

Of the five commanders I talked to, all unanimously agreed that the MEU should own outright the UAS. Colonel Mark Desens, commander of the 26th MEU, explained this position:

> It [MEU] doesn't have that capability [UAS] right now organic to it. Some people say, "Do you have to have everything organic to the ARG/MEU team?" My argument will be, "Yes", if you think that the ARG/MEU is the nation's crisis response, first on the scene to take action, then the answer is yes you need to have those tools. (2011)

c. Sea Base Versus Land Base

All of the commanders agreed on the topic of ownership; however, when asked where a UAS asset would be based or located, there was disparity. The commanders' differences of opinion centered around the ability to have a responsive system if it were land based.

The arguments raised in favor of a land-based system were (1) MEUs have C130 Hercules, communication detachments, and on some occasions F18 Hornets that support them from land bases near to the operating areas of the MEU and (2) the ability to have a large fixed-wing UAS that can carry increased loads and have increased endurance.

On the other side of the argument, the points raised were (1) on any major operation (such as the most recent Libya incursion or any day at Djibouti), space to

operate is very limited and (2) throughout the world, there are almost no countries that allow over-flight of unmanned aircraft, which severely limits the responsiveness of any land-based UAS.

d. Enabler

The impression that all of the MEU commanders gave me was that they believe the UAS is a key enabler. Generally speaking, UASs have become a high-demand asset; however, they have not yet become a requirement for operations.

B. Cost Estimates for Future UAS

1. Modeling Choices

I used Excel and Crystal Ball to model my WBS using the CERs developed in Chapter III. These programs performed the Monte Carlo method, randomly running through 10,000 trials using established assumptions. For my model, I assigned the assumptions around a preexisting UAS that best fit the mission capabilities that I derived from the survey.

For this thesis, I used the AH-6X Unmanned Little Bird as the basis of my assumptions. The AH-6X has a BriteStar forward-looking infrared (FLIR), which can provide ISR and has stations or “planks” that can fit varying weapons systems or payloads that support the other four top missions (strike, FAC[A], electronic warfare, or communications relay; Schreiner, 2008) Per Table 6, I programmed Crystal Ball with each variable’s probability functions closely matching the specifications of the AH-6X.

Table 6. Crystal Ball Variable Functions
(Boeing AH-6, n.d.)

Variable	PDF Value	Range
Empty Wt	Normal (1100,200)	4–4,589 lbs
MGTOW	Normal (3300, 150)	6–25,600 lbs
prod	Custom (0/.5, 1/.5)	0 or 1
Endurance	Triangle (8,10,12)	1–38 hrs
Payload Wt	Normal(1000,150)	1–1960 lbs
FF Year	Uniform(1973-2000)	1973–2000
VTOL	Custom (0/.1, 1/.9)	0 or 1
Sensor Wt	Normal (440,50)	40–625 lbs
Tracking	Custom (0/.5, 1/.5)	0 or 1
Avg Res	Triangle(.008,.08,.212)	.008–.212 nanometers
Altitude	Triangle(15000,18000,20000)	15–65,000 ft
FU Year	Uniform(1991,2002)	1991–2002
Range	Triangle (150,350,800)	0–2,400 naut. miles
Mobile Base/Tactical	Custom (0/.5, 1/.5)	0 or 1
Man Packable	Custom (0/.5, 1/.5)	0 or 1
Sys Qty	Uniform(1,8)	1–8

2. Model Analysis

After running the model, I predicted that there would be a normal distribution of the costs that would correspond to the AH-6X UAS system. Figure 11 was the distribution that I initially derived. Examining Figure 11 shows that there are two distinct nodes indicating that the cost model is clearly not normal.

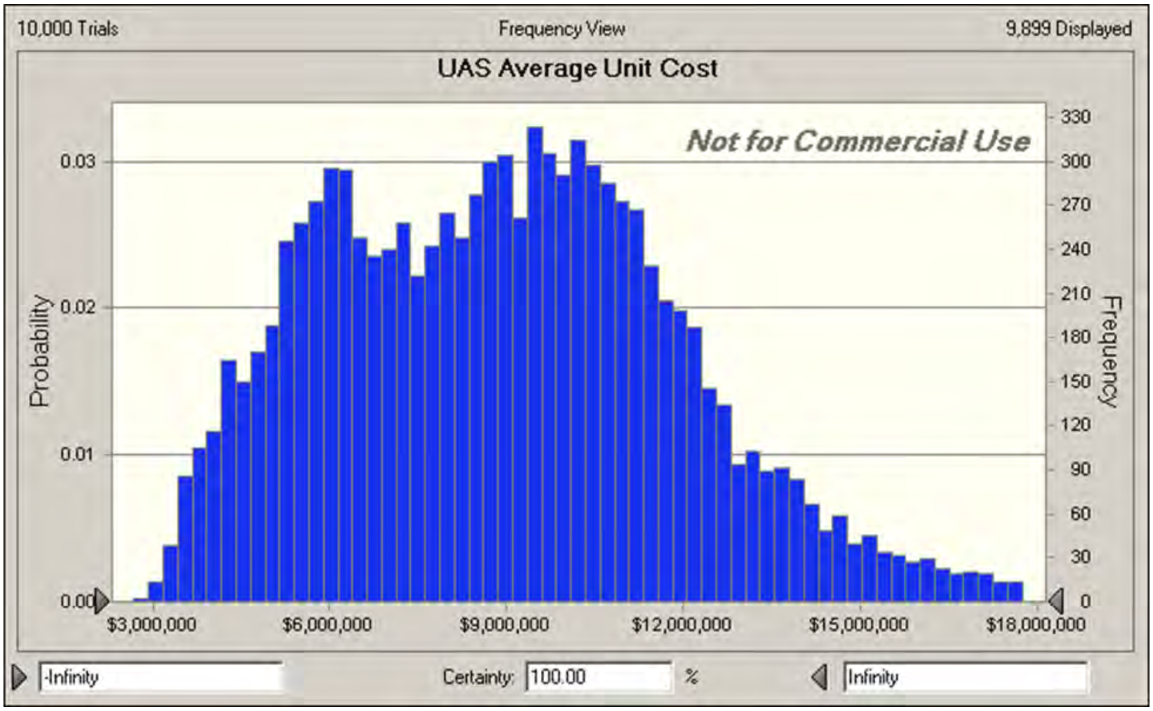

Figure 11. UAS Total Average Unit Cost

After examining the WBS levels and the forecasts associated with each level, I found that the air vehicle distribution had two very distinct nodes that were driving the total cost to not be normal (Figure 12).

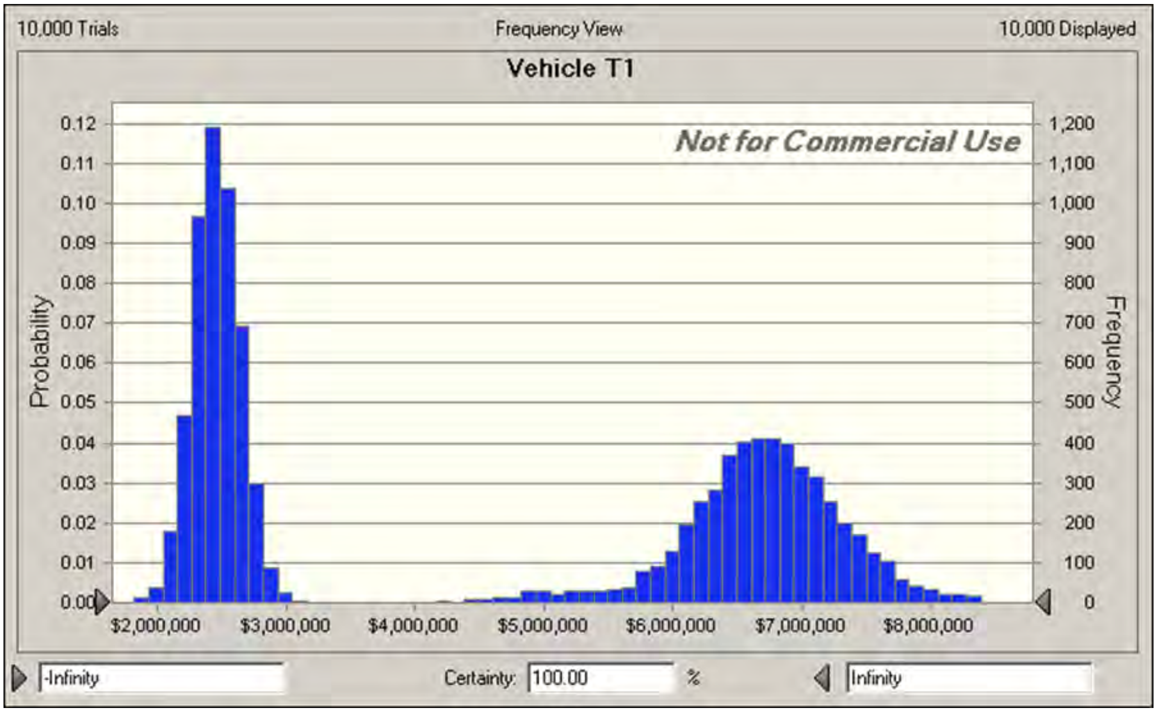

Figure 12. Average Air Vehicle Cost

When I examined the variable sensitivities found in Appendix D for the air vehicle T1 cost estimate, I determined three variables that most likely drove the variable costs. After running several iterations of the Crystal Ball while changing these three most sensitive variables, I determined that the binary cost variable “Prod” caused the largest distinct nodes in the cost estimates found in Figure 12. The smaller, more narrow node that centered at a lower cost was produced when Prod = 1 (i.e., the air vehicle was a production model of an aircraft). The more dispersed node centered at a higher cost was created when Prod = 0 (i.e., the air vehicle was a developmental aircraft).

C. Summary

From my analysis of the surveys and the MEU commander interviews, I was able to develop a generic list of missions for a future UAS program. The cost for a UAS program that supports these missions would be in the range of $8.5 million to $12.7 million per UAS depending on the type of air vehicle chosen for the program.

In Chapter V, I further break out the costs and make recommendations for the future of UAS in support of MEU operations.

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V. Conclusions and Recommendations

> *Whatever we do in acquisition, what we've got to do first is figure out what our strategy is . . . to figure out what we want the Armed Forces of the United States to be able to do . . . and then you build to that. You build toward an expeditionary Navy and Marine Corps. You build primarily toward very flexible and very adaptable platforms. You can't have the luxury anymore of single use platforms.*
>
> *—Secretary of the Navy Ray Mabus (2011)*

A. Conclusions

1. Future UAS Capabilities

Colonel Michael Hudson, commander of the 11th MEU, made the comparison between the UAS and the airplane pre–World War II. In the early days of naval aviation, many felt that the airplane was a useful tool, an enabler, but that it would never replace the battleship.

The UAS has the same status: a useful tool, an enabler. The U.S. has the technology and the knowledge to fire a Tomahawk missile hundreds of miles at low altitude or land a MV-22 "hands-off" in a desert. It is that same technology and knowledge that will permit unmanned systems to develop beyond an enabler into a requirement of modern warfare.

When a battleship was sunk using an airplane, the Navy demonstrated how the airplane could be more than just an enabler to operations. It became a requirement for operations. The UAS made that transition when it effectively demonstrated its offensive capabilities in Afghanistan by firing missiles at high-value targets. Unfortunately, the USMC has yet to make the move to evolve its UAS program. It is important that the USMC engages in the full capabilities of the UAS.

The surveys were clear as to what the top five mission sets should be for any future UAS program: (1) ISR, (2) strike, (3) FAC(A), (4) communication relay, and (5)

electronic warfare. In addition to these mission sets, the future system must have an endurance extending to 24 hours and will need BLOS control.

2. Cost Estimates for Future UAS

After determining the major cost driver in the total unit cost, I ran the model twice more. For the first iteration I set Prod = 1 while continuing to make use of original probability functions for the other variables. This iteration enabled me to determine the total costs associated with a production aircraft. The model produced the costs in FY03 dollars (with an 80% confidence) for a production aircraft:

- Air vehicle T1 cost = $2.6 million
- Total system per-unit cost = $8.45 million

For the final sampling of the model, I set Prod = 0 to determine the cost of a developmental aircraft. I continued to use the same probability functions for the other variables, and the model produced costs in FY03 dollars (with an 80% confidence) for a developmental or demonstrator aircraft:

- Air vehicle T1 cost = $7.2 million
- Total system per unit cost = $12.72 million

B. Recommendations

The current DoD acquisition policy is defined as evolutionary. The costing numbers are reflective of why the services should attempt to make use of production or commercial off-the-shelf (COTS) equipment.

With the anticipated shrinking DoD budgets, development of COTS equipment will be key to maintaining future capabilities with fewer dollars.

With respect to any future UAS programs, there are numerous examples of COTS aircraft that have demonstrated an unmanned capability. Two common examples are the Schweizer 333, which is being developed as the MQ-8 Firescout,

and the OH-6, which is being developed into the AH-6X. The latter is an excellent example of a platform that could support the multi-mission UAS. It can execute ISR and designate and shoot targets, all with a respectable 10-hour endurance. The AH-6X is also designed with a “plank” system that can support the addition of communication relay equipment or signals intelligence equipment. The AH-6X can support all of the top five missions recommended by the survey participants.

The AH-6X is not the final solution to the future needs of the USMC; however, it can be purchased today and in the fleet tomorrow. The USMC has an opportunity in the AH-6X to explore the full potential of a UAS in support of an MEU. This platform will enable the USMC to develop techniques, tactics, and procedures (TTPs); define the standard operating procedure (SOP) for UASs; and further define the USMC’s UAS needs in an operational environment.

I recommend that while the USMC develops SOPs and TTPs with a production aircraft like the AH-6X, it should look into developing a dedicated UAS to support the MEU. Currently, there is no fixed-wing or VTOL UAS designed specifically for ship use that can support the demanding needs of an MEU. Production aircraft will not meet the full requirements of the MEU as they stand.

This evolutionary approach to UAS will enable the USMC to refine its UAS requirement with a production system like the AH-6X while designing for the future. Regardless of the system developed, the USMC must invest in the next generation of unmanned systems to stay relevant and on the edge of modern warfare.

C. Follow-On Work

The following list points out some items of concern that could use additional attention to support the USMC plan to develop a new UAS program of record:

1. The ability of Navy amphibious ships to support the operation of a future UAS program.

2. Networking of UAS with other aircraft and ships to create a data network.

3. UAS TTPs in environments other than deserts.

4. Deck cycles with a long-endurance UAS.

5. Effect of disaggregated operations on UAS support of MEU operations.

6. Synergistic mix of Tier II, III, IV, and V UAS in support of MEU/MEB MAGTF

Appendix A. Survey Questions

This is the list of NPS Internal Review Board approved questions that were posted to SurveyMonkey. Question number 1 was the required consent question and per the board's protocol no one was allow to proceed with the survey without checking yes to the consent question.

1: Required Consent Question.

2. What is your primary MOS?

3. What is your MEU experience:

   Deployed with:

   1 MEU
   2 MEU
   3 MEU
   >3MEU
   Never part of MEU

4. What is your experience working with unmanned aircraft?

   I am an operator
   I regularly use UAS as part of my mission
   I regularly benefit from support provided by UAS
   I have never worked with a UAS

5. As UAS continue to develop, what do you think should be the primary mission of an unmanned aircraft to best support MEU operations? (If a UAS could do nothing else you would want it to do this…)

   Strike
   Cargo
   Communication Relay
   ISR
   CSAR
   CASEVAC
   Electronic Warfare
   FAC(A)(includes target designation)

Other (please list in comments)

6. If the USMC could develop a multi-mission UAS, what do you think would be the next best mission an unmanned aircraft could perform to support MEU operations?

   Strike
   Cargo
   Communication Relay
   ISR
   CSAR
   CASEVAC
   Electronic Warfare
   FAC(A)(includes target designation)
   Other (please list in comments)

7. Again, if the USMC could develop a multi-mission UAS, what do you think the tertiary mission (next best) an unmanned aircraft could perform to support MEU operations?
   Strike
   Cargo
   Communication Relay
   ISR
   CSAR
   CASEVAC
   Electronic Warfare
   FAC(A)(includes target designation)
   Other (please list in comments)

8. Again, if the USMC could develop a multi-mission UAS, what do you think a fourth mission (next best) an unmanned aircraft could perform to support MEU operations?

   Strike
   Cargo
   Communication Relay
   ISR
   CSAR
   CASEVAC
   Electronic Warfare
   FAC(A)(includes target designation)
   Other (please list in comments)

9. If this future USMC UAS can perform multiple missions, what do you think the least likely mission an unmanned aircraft would perform in support of MEU operations?

   Strike
   Cargo
   Communication Relay
   ISR
   CSAR
   CASEVAC
   Electronic Warfare
   FAC(A)(includes target designation)
   Other (please list in comments)

10. Additional comments/suggestions:

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Appendix B. Interview Questions

These are the questions used to drive the interviews with the MEU commanders:

1. What are your thoughts on current UAS capabilities?
2. Do you see a place on an MEU for unmanned systems?
3. Has there been a exercise/operation where you think a UAS or a UAS capability could have made a difference in execution?
4. What would a UAS need to be able to bring to the fight that would warrant taking a current capability/platform away from the MEU?

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Appendix C. Survey Question Responses for All Respondents

This appendix contains graphical representations of the responses of all of the survey participants.

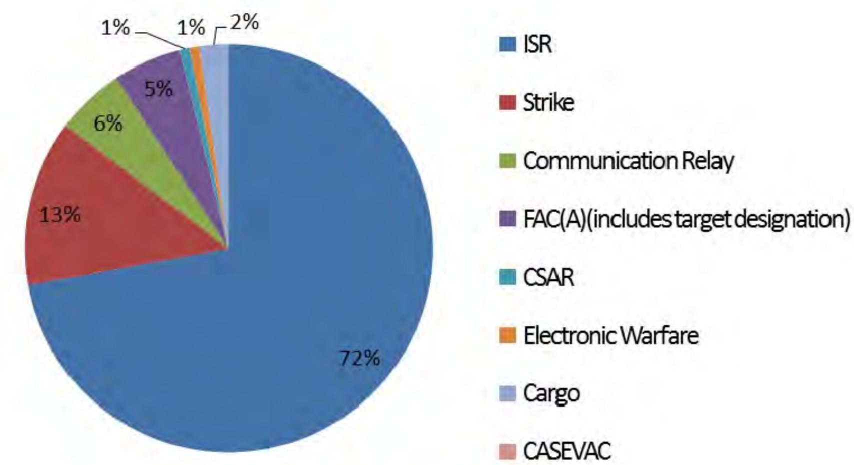

Figure 13. Primary Mission (All Respondents)

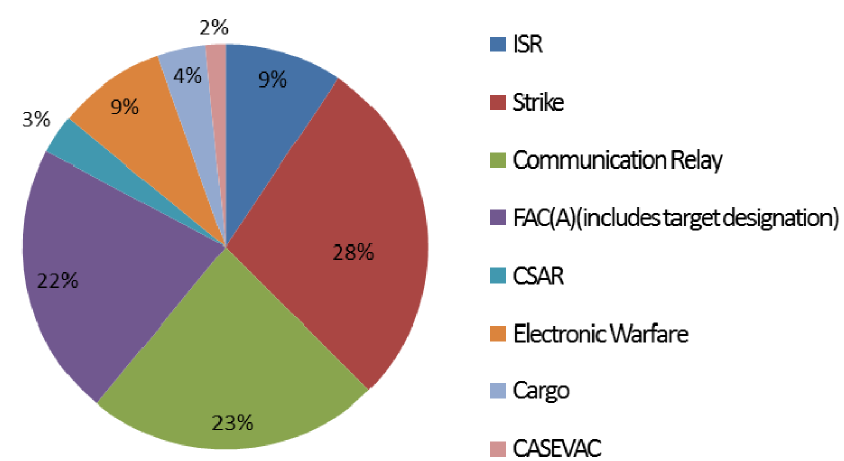

Figure 14. Secondary Mission (All Respondents)

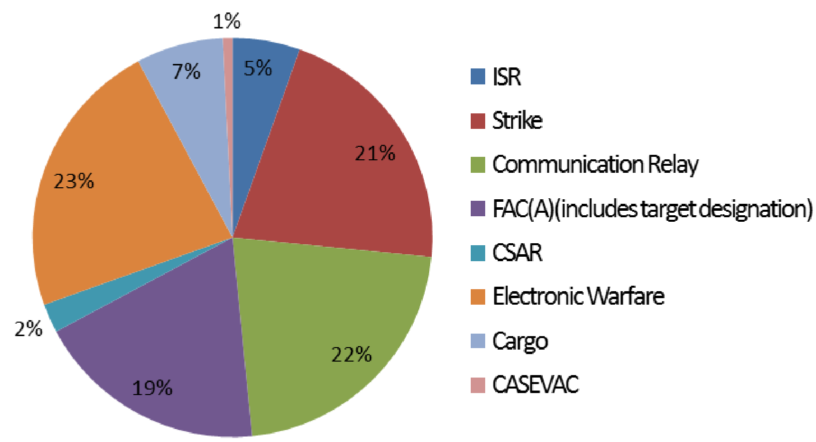

Figure 15. Tertiary Mission (All Respondents)

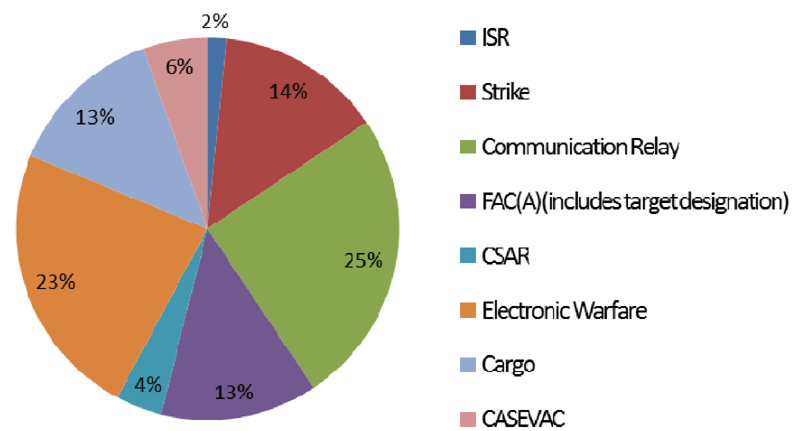

Figure 16. Quaternary Mission (All Respondents)

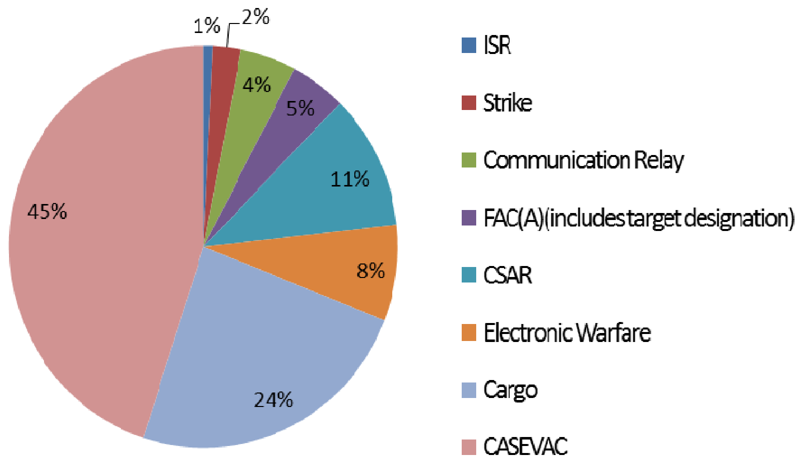

Figure 17. Least Desired Mission (All Respondents)

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Appendix D. Sensitivity Analysis

A sensitivity analysis was completed to determine which variables in each equation set had the most impact on the cost estimate. This appendix contains graphical representations of the analysis output.

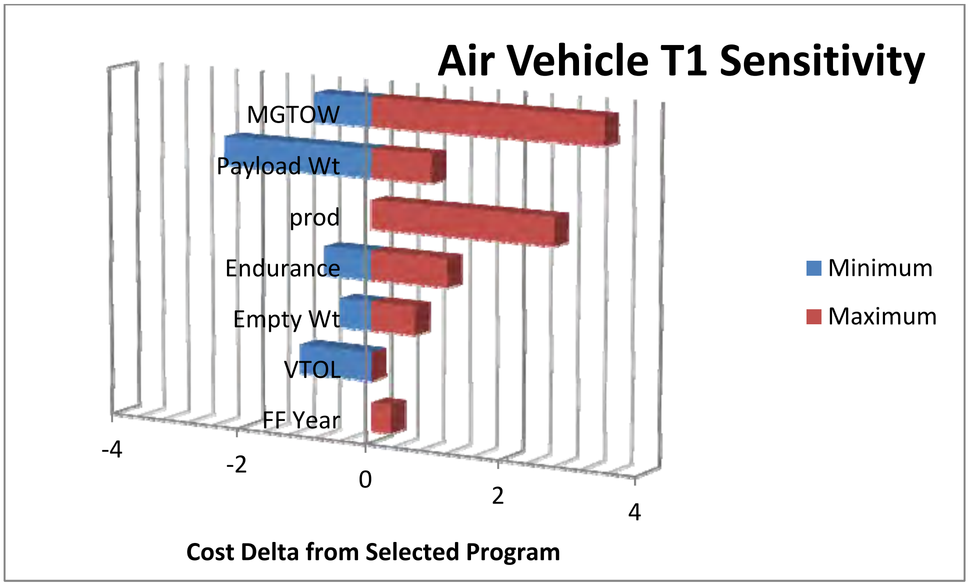

Figure 18. Air Vehicle T1 Sensitivity

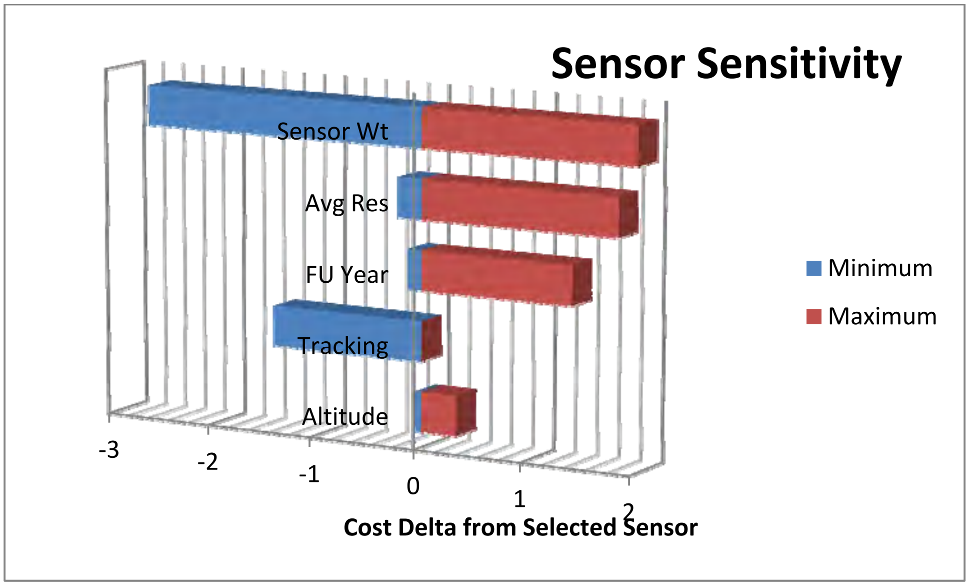

Figure 19. Sensor Sensitivity

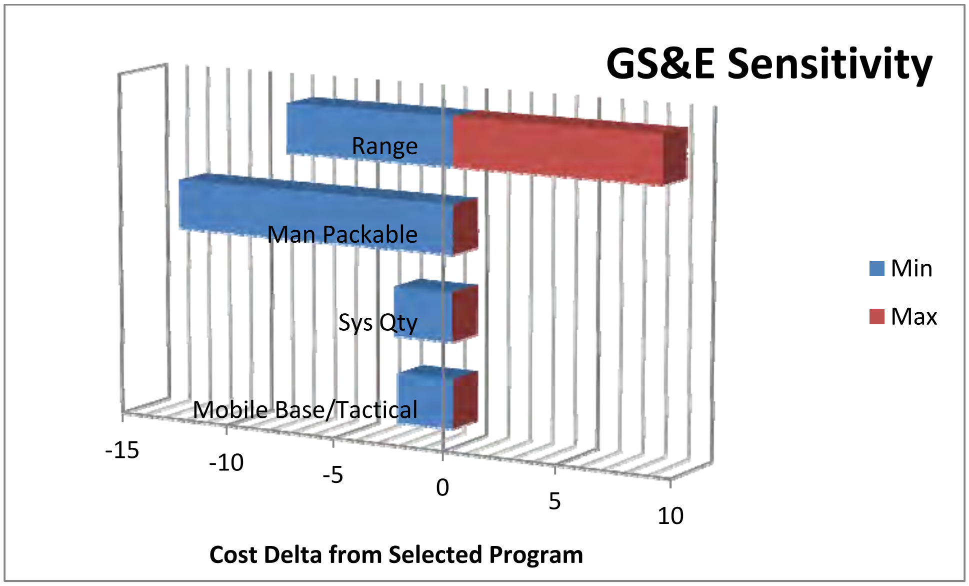

Figure 20. GS&E Sensitivity

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